2D and 3D High Resolution Seismic Reflection Surveys to Image the Subsurface

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ABSTRACT

This is the sixth in a series of fact sheets developed to provide information on technologies and strategies demonstrated at Naval Air Station (NAS) North Island under the Navy Environmental Leadership Program (NELP). This fact sheet provides information on the use of the 2-dimensional (2D) and 3-dimensional (3D) high-resolution seismic reflection survey techniques demonstrated at NAS North Island. These technologies were used to provide a better understanding of geologic heterogeneities and contaminant migration pathways at the site. The use of these non-intrusive techniques enabled the characterization of Site 9 at an unprecedented level of detail, saving the Navy more than $2 million in characterization costs and can potentially save millions of dollars more in remediation costs. The intent of this fact sheet is to encourage other Naval installations to consider using this technology at their facility.

BACKGROUND

On October 23, 1993, the Secretary of the Navy approved the implementation of NELP at NAS North Island, California and Naval Station Mayport, Florida. NELP was established to find new, improved, and more cost-effective ways to manage environmental programs at naval facilities. NELP initiatives at NAS North Island focus on identifying and demonstrating innovative cleanup, compliance, P2, and conservation technologies at reduced costs that will have a broad application Navy-wide.

As a result of past waste and resource management practices at NAS North Island, some areas of the installation are contaminated with various hazardous substances. One of these areas, Site 9 (a former chemical waste disposal area [Figure 1]) contains high concentrations of volatile organic compounds, semivolatile organic compounds, and metals in the soil and groundwater. To characterize the nature and extent of these contaminants, the Navy estimated that a drilling program consisting of approximately 150 borings on a grid over the 40-acre site would be required. This estimate was tentatively increased to 600 borings when it became apparent that complex hydrogeologic and contaminant distribution conditions

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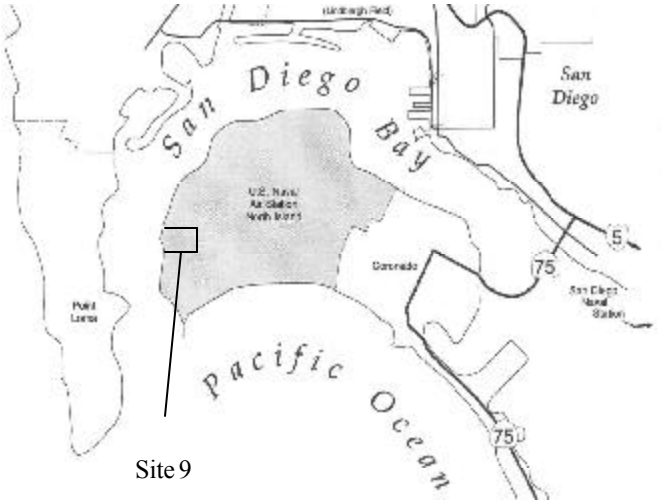

Figure 1 Site Vicinity Map

existed at the site, including the potential presence of dense non-aqueous phase liquid (DNAPL) and multiple confining layers. Because of the high characterization costs (approximately $4.5 million for the drilling program alone) and potential for inadvertently spreading contamination during an intensive drilling program, the Navy decided to characterize the site using the non-intrusive 2D and 3D high-resolution seismic reflection techniques developed by Resolution Resources, Inc. (RRI).

TECHNOLOGY DESCRIPTION

The high-resolution seismic survey techniques demonstrated at NAS North Island use the principles of seismic refraction and reflection: when a seismic or acoustic source is used to generate an impulse at the surface, seismic waves are induced that are either reflected by or refracted along subsurface interfaces of differing geologic strata. Receptors (geophones) at the ground surface record the time for a wave to travel from a surface source along an interface (refracted) or to bounce off an interface (reflected) and return to the surface. The data are collected by a seismograph. From this time-versus-distance information, it is possible to map the depth to the water table, clay lenses, and confining layers and to delineate subsurface fractures.

OPERATIONAL REQUIREMENTS

Resource requirements necessary to implement 2D and 3D high-resolution seismic imaging are minimal. RRI maintains all the necessary data acquisition and computer processing equipment, including seismographs, seismic source, geophones, and processing software. Installation support requirements include site access, availability of site-specific subsurface information, approval to use 2-way radios, and cooperation to minimize site noise.

SITE CHARACTERIZATION APPROACH

The general site characterization approach using 2D and 3D high-resolution seismic survey techniques begins with a review of available site characterization information, stereo pairs of aerial photographs for fracture trace analysis, and interviews with site personnel. This information is used to develop a conceptual model of the site which is then tested by imaging the subsurface first with a site-wide 2D seismic survey to verify the presence of suspected fractures, clay lenses, confining layers, and other stratigraphic features. Figure 2 illustrates an interpreted 2D seismic section. Based on the results of the 2D survey, one or more 3D surveys, which have greater resolution and accuracy than the 2D survey, are used to develop a more focused image of the areas of greatest interest, such as areas of anticipated DNAPL pooling.

DEMONSTRATION RESULTS

The Site 9 demonstration involved a 2D seismic survey consisting of seven seismic lines (totaling 15,840 feet) and two 3D surveys covering approximately 30.5 acres. The data from the seismic surveys were used to image the subsurface and were correlated with data collected from cone penetrometer tests, mud rotary borings, and hollow-stem auger borings to provide a detailed understanding of geologic heterogeneities and contaminant migration pathways at the site. Based on correlations with this data, the seismic survey data was shown to provide a vertical accuracy of 1 to 2 feet and horizontal accuracy of less than 5 feet.

At Site 9, DNAPLs have migrated through approximately 10 feet of vadose zone soils into the underlying saturated zone. The seismic data was able to define several confining layers and previously unknown faults at the site, which appear to control contaminant migration. The seismic data indicate that a discontinuous clay layer is present at a depth of about 35 to 40 feet below ground surface (bgs) and that a continuous clay layer is present at about 100 feet bgs. Based on the seismic reflection data, the thinner, upper confining layer is not believed to be a major influence on contaminant transport. One purpose of the seismic surveys was to locate depressions in the continuous clay layer where DNAPLs may have collected and pooled. Wells could then be drilled into the DNAPL pools to allow removal of free DNAPLs. The seismic data, however, indicate that the clay layer may be breached by faults and may not collect DNAPLs. A 3D seismic image of the continuous clay layer is shown on Figure 3.

To determine if DNAPL pools were present at Site 9, temporary wells were drilled into three depressed areas in the continuous clay layer identified by the seismic data. These areas were thought to be the most likely areas for DNAPLs to collect if fracturing was not too extensive. Free product was not found in any of the wells. It was concluded that the clay layer was, indeed, too fractured and faulted to hold DNAPLs, as was indicated by the seismic data. The identification of faults also provided an explanation for why the major plume at the surface of the clay layer at 100 feet bgs migrated southwest instead of west, the downdip and downgradient direction. The implications of this finding on remedial alternative selection and system design were enormous. Instead of

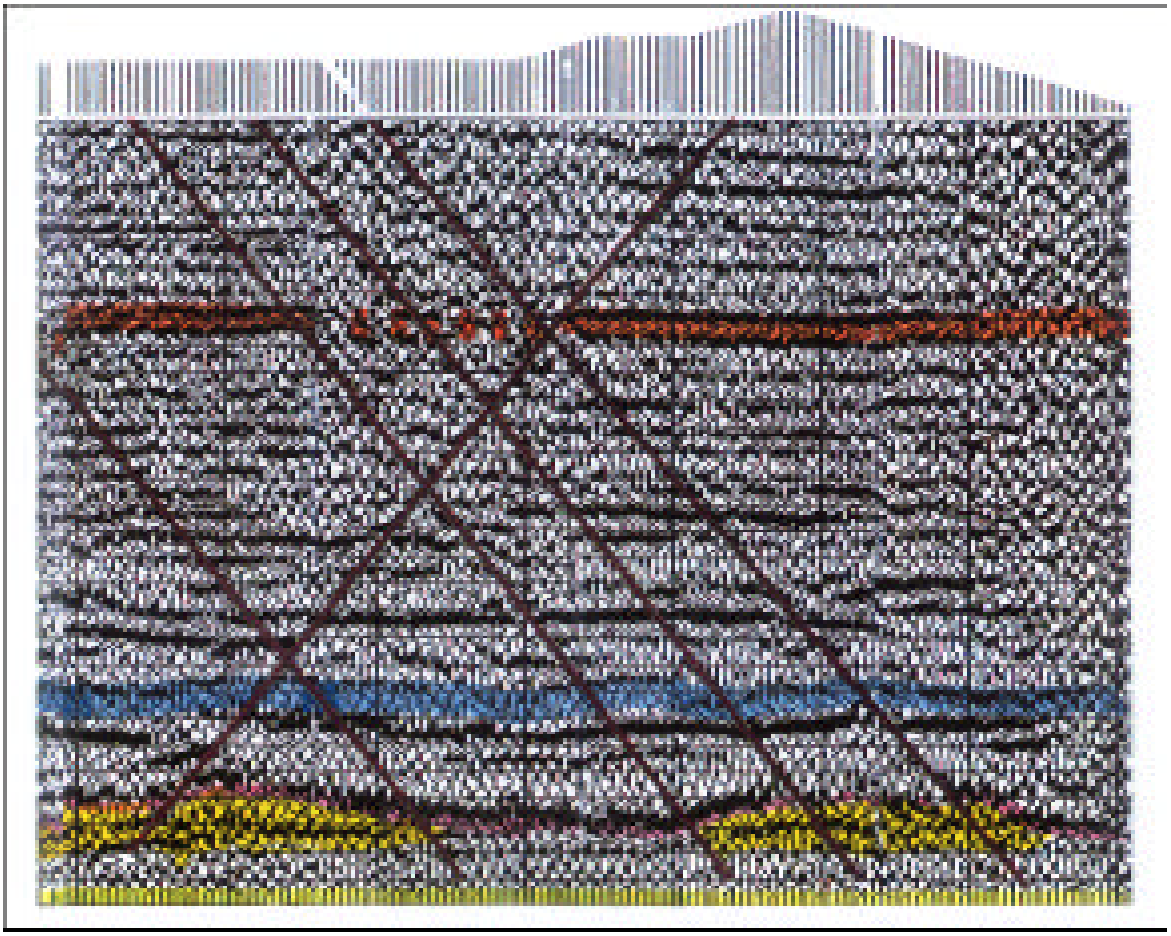

Figure 2 Cross-Section of Site 9 Showing Faulting and Stratigraphy (Coarse grained channel deposits in yellow; discontinuous clay layer in blue; continuous layer in brown)

installing costly pump-and-treat systems to remove DNAPLs, remedial selection and design now focuses on dissolved phase contaminants in the saturated zone and soil gas in the vadose zone. In addition, sufficient information was obtained to optimize the remedial system design and placement at the site, thereby increasing the system effectiveness and reducing the overall cost and time requirement for site remediation.

As a result of the seismic work, evidence was obtained that suggests DNAPLs affect the acoustic signature of saturated sediments. With this information and further development, high-resolution seismic imaging may provide a means of imaging DNAPLs directly without drilling, sampling, and analysis.

BENEFITS

The 2D and 3D high-resolution seismic imaging techniques provide a non-intrusive and cost-effective enhancement for site characterization. The Site 9 demonstration showed the following advantages of this technology:

- The seismic reflection technique provides a more detailed characterization of hazardous waste sites than traditional drilling programs. The ability to produce a 3D image of a site rather than infer data from a limited number of borings will aid decision makers in the eventual selection, design, and placement of remedial systems.

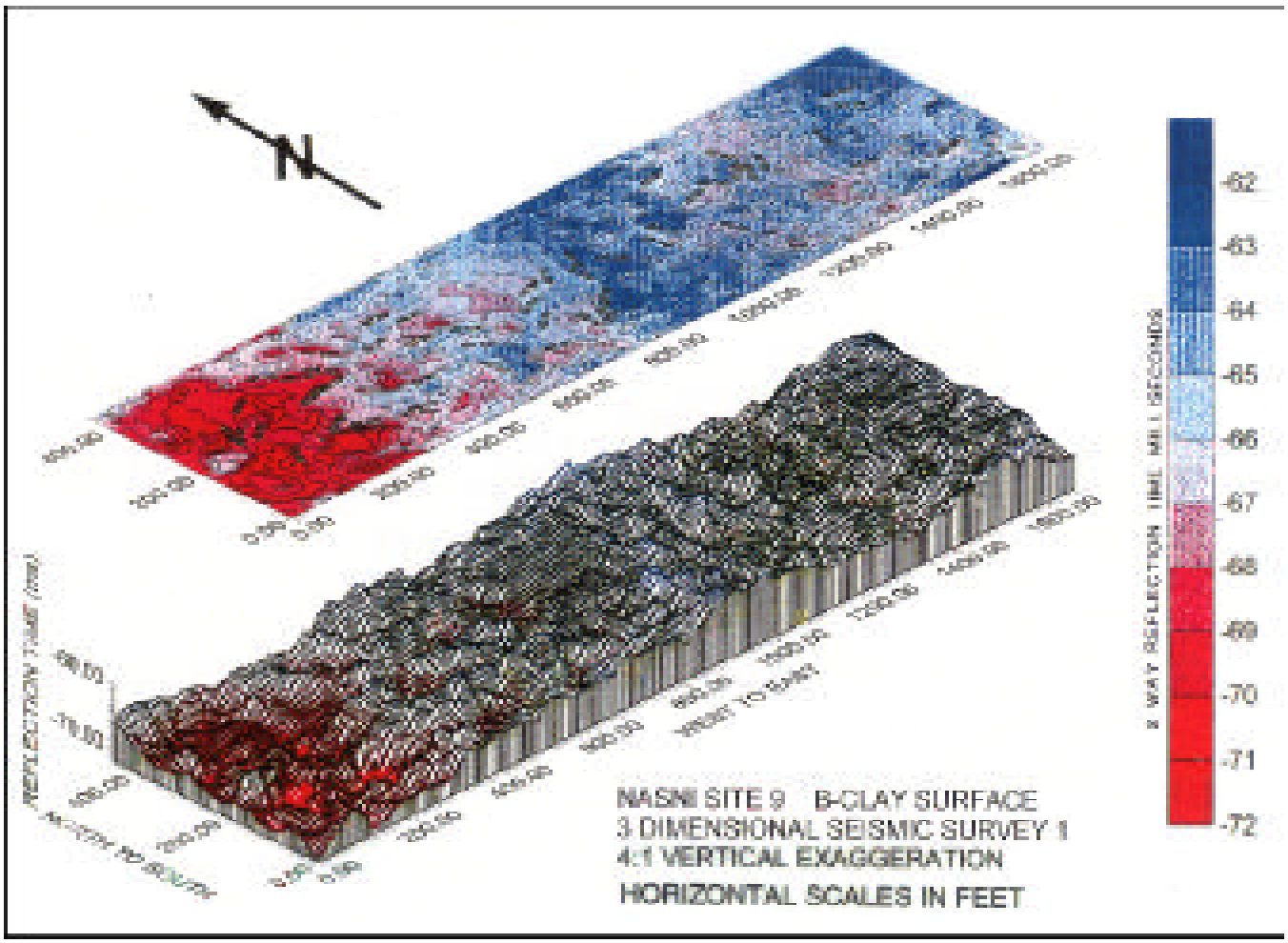

Figure 3 3D Seismic Image of the Continuous Clay Layer

- The seismic reflection technique can be applied quickly in comparison to traditional approaches to collecting site characterization and remedial design data; thereby reducing the time required to characterize a site.

- The number of soil borings and groundwater monitoring wells required for site characterization will be significantly reduced. By reducing the number of borings and wells, the Navy will save time and money during site characterization and minimize potential cross contamination and contaminant disposal costs.

- The technique provides the data necessary to develop an accurate conceptual model of a site; thereby, potentially reducing the time and cost for cleanups. Because more precise information is available, a better estimate of the project budget and schedule can completed.

- Contaminant pathways can be better under stood resulting in the improved design and efficiency of the selected remedial system. For example, optimal placement of recovery wells can be achieved with a 3D image showing depressions, confining layers, and other likely DNAPL collection points in the subsurface.

LIMITATIONS

The 2D and 3D high-resolution seismic survey techniques can be limited by the following factors:

- Unconsolidated soil conditions such as certain fill materials or landfills may significantly reduce signal return.

- Steeply dipping beds will cause the induced seismic signal to reflect and refract away from the surface.

- Excessive noise from heavy vehicle traffic, air traffic, and fixed machinery may interfere with collection of seismic data.

During seismic reflection survey activities at Site 9, RRI was able to overcome problems and interferences caused by the presence of uncosolidated sediments, high water table, pavement, and air traffic.

COSTS

The cost to implement 15,840 linear feet of 2D and 30.5 acres of 3D high-resolution seismic survey at NAS North Island was about $250,000. This included a literature review, fracture trace analysis, 2D and 3D data collection and processing, data interpretation, and reporting. NAS North Island estimates that the survey saved the Navy over $2 million in characterization costs. In addition, by using the seismic data to refine the site conceptual model and to optimize placement and design of required remedial systems, the Navy anticipates saving millions of dollars more in reduced remediation costs.

SOURCES OF ADDITIONAL INFORMATION

Technical implementation information can be obtained from the following contacts:

William Collins
Southwestern Division
Naval Facilities Engineering Command
2585 Callagan Highway
Naval Station San Diego
San Diego, California 92136-5198
Phone: (619) 556-9901
Fax: (619) 556-8929
E-Mail: (wecollins@efdswest.navfac.navy.mil)

Mary-Linda Adams or Brian Herridge
Resolution Resources, Inc.
3636 Goodwin Road
Ionia, Michigan 48846
Phone: (517) 647-1832
Fax: (517) 647-2862

Additional Information about the Navy Environmental Leadership Program can be obtained on the Internet WWW Site at:

http://nasni.navy.mil/~nelp/nelp.htm

MAILING LIST

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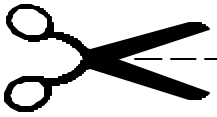

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